ACKNOWLEDGMENTS

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The Bureau of Land Management, U.S. Department of Interior, provided financial assistance for the study and supplied timber contract data and personnel at the District level to help conduct field measurements.

The U.S. Forest Service, Region 6, assisted in supplying timber contract data and making available personnel on each National Forest to help conduct field measurements.

METRIC CONVERSIONS

1,000 cubic feet = 28.3 cubic meters

1 cubic foot per acre = 0.070 cubic meter per hectare

1 inch = 2.54 centimeters

1 mile = 1,609.344 meters

A TECHNIQUE FOR PREDICTING LOGGING RESIDUE VOLUMES IN THE DOUGLAS-FIR REGION

Reference Abstract

Howard, James O.
1978. A technique for predicting logging residue volumes in the Douglas-fir region. USDA For. Serv. Res. Pap. PNW-235, 14 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

This report presents results of a study using regression equations to predict the volume of logging residues before harvesting occurs. Procedures are discussed and equations presented for Bureau of Land Management and National Forest lands in western Oregon and western Washington.

KEYWORDS: Residue measurements, clearcutting systems, computation, Oregon (western), Washington (western).

RESEARCH SUMMARY

Research Paper PNW-235

1978

This report presents the findings of a study for determining the feasibility of predicting the volume of logging residue on clearcuts prior to harvesting. Data were collected from 160 clearcuts on Bureau of Land Management (U.S. Department of Interior) and National Forest (U.S. Department of Agriculture) lands in western Oregon and western Washington. Multiple regression techniques were used to develop equations relating preharvest stand and economic characteristics to measured residue volumes.

The regression procedure resulted in the development of individual equations for each of four Bureau of Land Management Districts in western Oregon. Separate equations were also derived for the National Forests in Oregon and those in Washington. Regression correlation coefficients (R^2) for the Bureau of Land Management equations ranged from 0.61 to 0.88, and were 0.44 and 0.51 for the National Forest equations.

Study results indicate that regression techniques as described have much potential for providing adequate estimates of logging residue volumes before harvesting occurs. Further testing and refinement of the procedure could provide the forest manager with a useful tool for making residue management decisions.

Contents

The Problem

Logging residues continue to be a major problem facing land managers in the Douglas-fir region. While volumes have been declining, logging residues are still being produced in rather large quantities. A 1969 study[1/] indicates volumes of 2,600 to 4,500 cubic feet per acre on Bureau of Land Management (BLM) and National Forest clearcuts. The volume on some areas was as high as 10,000 cubic feet to the acre. Reducing the volume of residues resulting from clearcut harvesting has been an objective of forest managers. Increasing pressures related to environmental impacts and decreasing timber supplies have intensified the problem in recent years.

An effective job of land management requires that the treatment of logging residues be an integral part of timber sale planning. Decisions concerning which of several residue treatment alternatives to use are frequently made prior to release of the sale for bidding. Thus the forest manager is faced with the problem of needing an estimate of the volume of residue before it is created. Personal experience has traditionally been the source of information for this decision.

The objective of this study was to determine the feasibility of using a regression equation approach to predict logging residue volumes prior to harvest. The guiding purpose is to provide the forest manager with a quantitative tool that will yield an acceptable estimate of the expected volume of logging residue for an individual clearcut unit. It is also felt that results from this study will make an important contribution to current research endeavors by identifying significant correlations between sale characteristics and residue volume.

The study was designed to produce regression equations utilizing information generally known to the forest manager prior to releasing the contract for bidding. These equations will produce an estimate of logging residue in terms of cubic feet per acre, thus giving the forest manager an objective basis for decisions related to residue abatement.

The study was conducted on BLM and National Forest lands in the Douglas-fir region of Oregon and Washington. All areas sampled were clearcut logged during calendar years 1972 and 1973. The line intersect method[2/] [3/] was used to obtain estimates of the volume of residue for the clearcut areas sampled.

1/ Howard, James O. Logging residue in Washington, Oregon, and California, volume and characteristics, USDA For. Serv. Res. Bull. PNW-44, 26 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

2/ Warren, W. G., and P. F. Olsen. 1964. A line intersect technique for assessing logging waste. For. Sci. 10(3):267-276, illus.

3/ Van Wagner, C. E. 1968. The line intersect method in forest fuel sampling. For. Sci. 14(1):20-26, illus.

Study Methodology

In general, the study involved (1) selection of the independent variables and sample areas; (2) measurement of the logging residue on each clearcut area; (3) collection of data for the independent variables; and (4) processing the data in a regression program. This section of the report describes the process involved in determining the BLM and National Forest predictive equations.

The first step in the process was the selection of the independent variables. This was guided by a number of considerations: (1) data for each variable had to be readily available or collectable, (2) this information had to be available to the forest manager prior to release of the timber sale for bidding, and (3) each variable was assumed to have a direct or indirect correlation to the volume of logging residue. A preliminary list of variables was sent to each agency for review. Although these were the basic variables for which data was collected, combinations or exponential forms of these variables were also used in the analysis.

Listed below are the variables selected for the analysis:

(1) Stand age
(2) Gross cruise volume, per acre
(3) Percent stand defect
(4) Average slope percent
(5) Size of clearcut
(6) Average stand diameter
(7) Percent of exportable volume
(8) Estimated distance to nearest processing center
(9) Estimated haul distance on secondary roads
(10) Percent of whitewoods in stand
(11) Percent of western redcedar
(12) Appraised stumpage value
(13) Current utility lumber price index
(14) Current general lumber price index

Detailed definitions of these variables are included in the appendix. Many other variables were considered but were excluded from the analysis because of lack of data or because they were highly correlated to other variables.

A total of 160 clearcut areas, 80 each on BLM and National Forest[4/] lands, were randomly selected from all qualifying areas. The sample was allocated by BLM District or National Forest.[5/] By request of the BLM, 20 samples

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4/ Due to a lack of certain data elements, only 79 clearcuts were included in the National Forest analysis.

5/ All National Forests in western Oregon and western Washington were included in the study except the Rogue River, where no qualifying clearcuts were found.

were allocated to each of four districts. Not included in the BLM portion of the study were the Medford District and lands in western Washington. The Forest Service sample was allocated to each Forest on the basis of the proportion of the timber harvest in each Forest to the 1972 total. The next step in the study was to determine the population of clearcuts to be sampled. To be part of the population, each clearcut had to meet the following criteria:

(1) each area had to be 5 acres or more in size,
(2) the residue on the area could not have been piled or burned prior to measurement,
(3) logging had to be completed during calendar years 1972 and 1973, and
(4) cable yarding had to be employed over most of the area.

In addition, no unique sales, such as for salvage of fire or insect damage, were included in the sample population.

Each agency provided a list of all clearcut units that met the criteria of the study. The sample areas were randomly selected from these lists. Alternative samples were drawn in the event some of the primary areas failed to meet study standards at the time of residue measurement. A list of the sampled areas was sent to each agency to verify the status of each clearcut unit.

Fieldwork began after determination of the sample areas was completed. The volume of logging residue on each sample area was estimated using the line intersect method.[6] Forty 200-foot transects were laid out on a systematic grid on each of the clearcut areas (fig. 1). All logging residue material intersected by these lines was measured. For this study, logging residue was defined as all dead material, regardless of origin, 3.5-inch d.i.b. or larger, at least 4 feet in length, and not rotten to the point of losing form (i.e., punky, spongy logs were not measured). Measurements recorded for each piece of residue were diameter inside bark, at the point of intersection with the transect (see fig. 2 in the appendix), and percent soundness on a chippable basis at the point of diameter measurement.

After completion of the fieldwork, data for the independent variables were collected from each agency. A final list of sample units, definitions, and examples of needed information was sent to each BLM District and National Forest. Date of initiation of logging was requested to provide a basis for office computation of the price index variables. After the data were collected, all information was keypunched in preparation for statistical analysis.

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[6] Howard, James O., and Franklin R. Ward. 1972. Measurement of logging residue--alternative applications of the line intersect method, USDA For. Serv. Res. Note PNW-183, 8 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

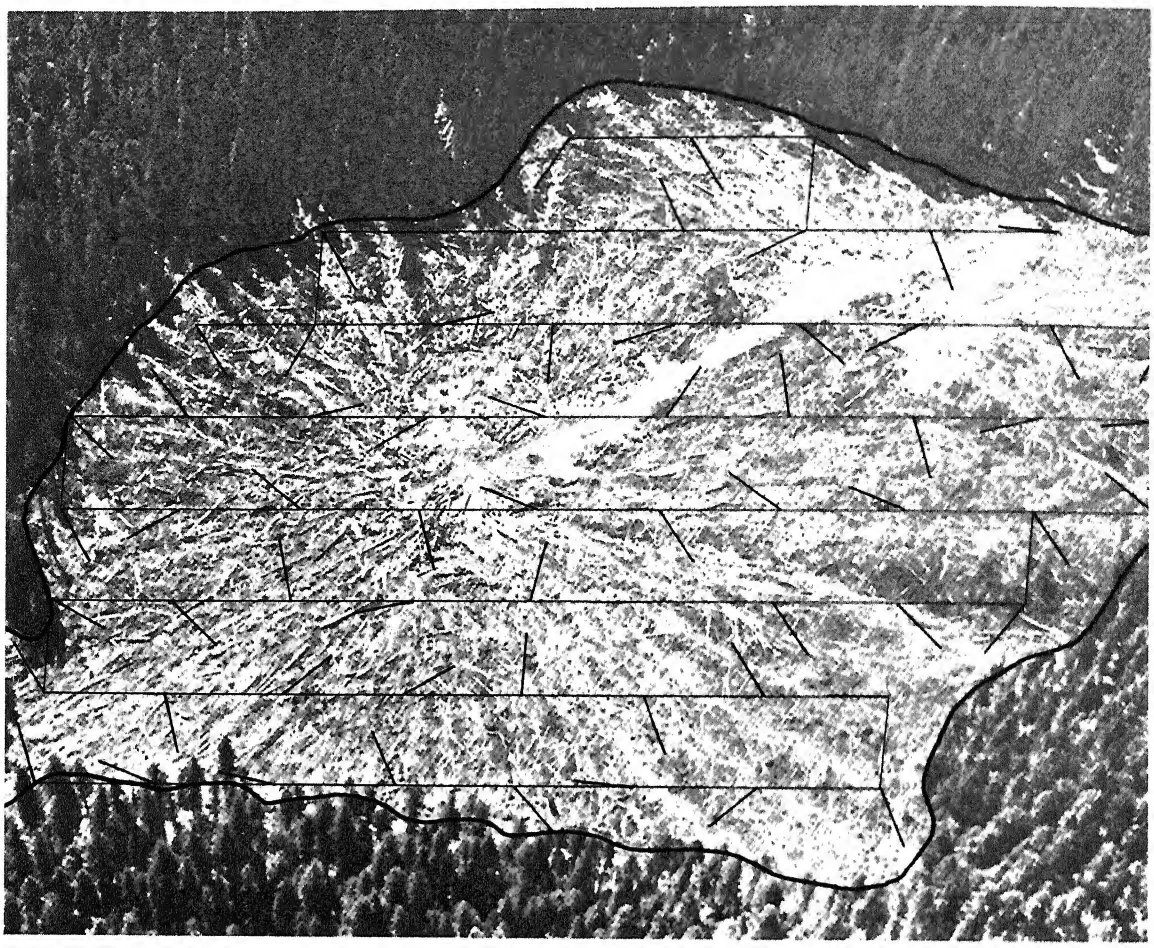

Figure 1.--Symbolic representation of sampling grid applied to clearcut area.

A multiple regression program, REX,[7] was used to derive a set of regression equations for each agency.[8] This program generates all possible combinations of the independent variables with a particular dependent variable. The combination with the smallest residual mean square error is selected as the best equation for that particular set of variables. Logging residue, the dependent variable in the analyses, is expressed in terms of cubic feet per acre. Both gross and net volumes of residue were tested.

In addition to the basic set of variables, various combinations, products, cross products, and exponential forms were analyzed. The samples were also arranged in various geographic strata to provide the best equations possible from the existing data.

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[7] Grosenbaugh, L. R. 1967. REX--Fortan-4 System. USDA For. Serv. Res. Pap. PSW-44, Pac. Southwest For. and Range Exp. Stn., Berkeley, Calif.

[8] All clearcuts were given equal weight in the regression analysis.

Results of the Study

Shown below are the proposed predictive equations for each agency. Although other combinations of variables and geographic areas were analyzed, these equations represent the smallest residual mean square error for each BLM District or National Forest. Logging residue is expressed in terms of cubic feet per acre, gross volume.[9]

Bureau of Land Management

Coos Bay:

$$\text{Logging residue} = 19{,}863.7 - 84.726X_1 - 127.500X_2 - 53.153X_3 - 613.823X_4 + 18.248X_5 + 6.8931X_{10} + 0.55367X_{11} + 0.00105283X_{13}$$

Eugene:

$$\text{Logging residue} = 25{,}333.9 - 503.781X_1 + 74.135X_2 - 322.342X_3 - 214.939X_4 + 17.362X_5 + 6.14494X_{11} + 0.00444556X_{13}$$

Roseburg:

$$\text{Logging residue} = 4609.8 + 63.175X_1 - 118.786X_3 + 64.474X_4 + 43.321X_5 + 82.787X_6 - 74.687X_7 - 0.0693392X_{12} + 0.03454652X_{13}$$

Salem:

$$\text{Logging residue} = -40{,}774.0 + 792.213X_1 + 35.777X_2 + 629.868X_3 - 134.135X_6 + 107.196X_7 - 10.14438X_{11} - 0.01705336X_{13}$$

U.S. Forest Service

Western Oregon:

$$\text{Logging residue} = 2201.9 + 19.016X_3 + 46.953X_4 + 16.242X_5 - 13.711X_6 + 82.582X_8 + 21.672X_9 - 0.8673X_{10}$$

9/ Gross volume represents the total mass of a piece of residue, whereas net volume represents only the sound (chippable) portion.

Western Washington:

$$\text{Logging residue} = 2836.1 - 54.555X_2 + 22.705X_3 + 2.4385X_{10}$$

Examples of the use of these equations are included in the appendix.

The independent variables used in these equations are:

Basic variables[10/]

X_1 = clearcut size (acres)

X_2 = average slope percent

X_3 = cruise volume (thousand board feet per acre)

X_4 = percent stand defect

X_5 = appraised stumpage value (dollars)

X_6 = utility lumber price index

X_7 = general lumber price index

X_8 = percent western redcedar

X_9 = percent exportable volume

Definitions of these variables are included in the appendix.

Derived variables[10/]

X_{10} = (average slope percent) x (percent stand defect)

X_{11} = (clearcut size) x (cruise volume)

X_{12} = (clearcut size) x (cruise volume) x (appraised stumpage)

X_{13} = $(\text{cruise volume})^3$

Table 1 gives some of the important statistics for each of the equations.

These equations were designed to yield an estimate of residue volume for a specific clearcut using information available during the normal timber sale process. Useful

10/ Basic variables are those for which data was collected; derived variables are some combination or form of the basic variables.

Table 1--*Statistical parameters for area equation*

Areas	Number of sample units	R^2	F-value[1/]	Mean-squared-residual	Standard error of estimate
BLM Districts:					
Coos Bay	20	0.88	10.12	.2066	592
Eugene	20	.78	6.06	.3490	918
Roseburg	20	.61	2.19	.6668	744
Salem	20	.77	5.78	.3623	1,061
National Forests:					
Western Oregon	52	.51	6.54	.5680	1,314
Western Washington	27	.44	7.18	.6368	565

1/ The F-value is the total fit of all variables for each equation.

results from the equations are quite dependent upon the accuracy of the data for the independent variables. Thus, the integrity of the predictions can only be maintained by insuring accuracy and nonbias in the gathering of data for these variables.

In general these equations would not be used for areas with unique characteristics, i.e., with values of the dependent variables far exceeding the range of the sample units. For example, a 3-acre clearcut, tractor logged to salvage fire damage might yield unreasonable results if an equation was used to predict the volume of logging residue. Table 2, in the appendix, shows the range of values from the study for certain variables.

The signs of the coefficients of the independent variables do not necessarily indicate direct cause and effect relationships. What can be inferred from these signs is a positive or negative correlation between a particular variable and residue volume. For example, if the sign of a specific variable is positive, it indicates that the volume of residue will increase proportional to the value of that variable, other variables held constant. The statement cannot be made that this variable <u>causes</u> residue volume to increase. The paradox of the implication of cause and effect can be seen in the changing sign of the coefficient of a specific variable from equation to equation.

Comments on the Findings

The results of this study indicate that multiple regression techniques can be used to derive equations for predicting the volume of logging residue for an individual

clearcut area. These equations can be used to assist in making residue treatment choices for a given sale, or to array estimates for all sales in an area to set priorities for treatment within a residue management program.

The reported equations were accepted as the best available within the constraints of the study. Further manipulations of the data might possibly have yielded improved results, however, the gains (increased R^2) would not warrant the added effort. The R^2 values for the BLM equations are much better than had been expected. Although not out of reason, the lower R^2 values for the National Forest equations are not readily explainable. Apparently, factors, or combinations of factors, exist that were not taken into account by the study. It is very probable that better results would be attained by following the study procedure for an individual National Forest. With the small number of samples for a single Forest, this hypothesis could not be tested in the current study.

Possibilities for improving these equations lie mainly in narrowing the geographic area of study, and including presently untested variables. Obviously, there are factors not examined in this study that affect the volume of residue created by clearcutting. This is evident by the amount of unexplained variation ($1-R^2$) in the current analysis. Many of these factors may, however, be unique to a limited area and not useful in a region-wide approach to residue prediction.

Regression analyses were also run using post-bidding independent variables and net volume of residue as the dependent variable. The use of post-bidding variables, such as bid price of stumpage rather than appraised stumpage, did not improve the equations. Rather, the opposite was true; R^2 decreased when these changes were introduced. Also, using the net volume of residue as the dependent variable led to lower R^2 values in most cases. This was expected because of the subjectivity involved in estimating the sound portion of residue material. The study focused on the gross volume, however, since most residue treatment decisions are related to the total mass of material rather than just the sound portion.

The equations developed in this study do not necessarily apply to timber sales in other geographic areas or for other ownerships within the study area. The biggest problem lies with the different natures of timber between areas and the different management objectives between owners. It is possible, however, that testing the equations in other areas might prove their acceptability for estimating logging residue in those areas.

Use of these equations to derive estimates of residue volume may be tempered by on-the-ground knowledge. In some areas, the forest manager may be aware of special circumstances

regarding a sale that indicate a modification of the predicted volume. For example, information concerning the potential purchaser of a sale makes it possible for the forest manager to adjust the predicted volume up or down. Unfortunately, in most cases the purchaser is not known prior to acceptance of a successful bid, thus hampering the use of this knowledge for pre-bid purposes.

Since results of this study indicate that regression equations can serve as predictors of clearcut residue volume, the next step is to test the equations in each of the study areas. This is a relatively inexpensive procedure and done to insure that conditions have not significantly changed so as to invalidate the relationships suggested by the equations and that characteristics of the samples are representative of the clearcuts in the area of use. The procedure for testing is similiar to that previously described. That is, the residue on a number of clearcuts is measured using the line transect method, data is collected for the independent variables; and this information is put into the predictive equation. The resulting estimates can then be checked against the measured volumes for accuracy. Large discrepancies for all test clearcuts might indicate the need to develop an equation unique to the particular area. If the predicted volumes are acceptably close to the measured volumes, the equation could be used as presented.

Due to the lower R^2 values for the National Forest equations, it may be necessary to develop new ones. This could be done at the Forest level, or for groups of Forests. Development of new equations would be relatively inexpensive in terms of time and money following the procedure outlined above. This process would also afford the opportunity to test new variables thought to be significant at the local level.

Once adopted, the equations should be updated periodically to account for changing conditions. This procedure would require little effort--especially if the regression program was maintained at a central location.

Appendix

DEFINITIONS

Following are the definitions and valuation units for each of the independent variables examined in this study. Only the basic variables are included since the derived variables are combinations, cross-products, or power terms of the basic variables.

Stand age is the estimated age of the stand to be cut to the nearest 10 years.

Cruise volume is the estimated gross volume per acre of the clearcut unit, to the nearest thousand board feet.

Percent stand defect is the estimated percent defect of the stand to be cut, to the nearest whole percent. This is reflected by $\frac{\text{gross cruise vol-net cruise vol.}}{\text{gross cruise volume}} \times 100$.

Average slope percent is the estimated average slope percent of the clearcut unit, to the nearest 5 percent. This may require that sample requirements be made. Care must be taken that the estimate reflects an overall average for the entire unit.

Clearcut size is the actual size of the clearcut unit, to the nearest whole acre.

Average stand diameter is the estimated average diameter b.h. of the stand to be cut, to the nearest inch.

Export percent is the percent of the stand volume that can legally be exported, to the nearest percent.

Distance to processing center is the estimated mileage to the processing center used in the appraisal, to the nearest 5 miles.

Secondary road distance is the estimated mileage of log hauling on nonpaved roads, to the nearest 5 miles.

Percent whitewoods is the estimated percent of total stand volume comprised of hemlock and true firs, to the nearest 5 percent.

Percent western redcedar is the estimated percent of total stand volume comprised of western redcedar, to the nearest 5 percent.

Appraised stumpage is the average stumpage value (appraisal) for the stand, to the nearest dollar; i.e., average dollars per MBF for all species.

Utility lumber price index is the computed price index for Utility-Economy grade lumber, to the nearest dollar. This index is computed by using information published by Western Wood Products Association (WWPA) in a monthly publication titled, "Monthly F.O.B. Price Summary Past Sales-Coast Mills." Prices are given for key items. The Utility price index used in this study is computed by taking 0.57 times the reported

price for Douglas-fir dimension, dry surfaced 4-inch Utility lumber plus 0.43 times the reported price for Douglas-fir dimension, dry surfaced Economy lumber. To account for the fact that these data are published with a one month lag, all values used in the study were for the month following initiation of the logging of the sample unit. For example, the January 1973 issue of the WWPA report shows Douglas-fir dimension, dry surfaced 4-inch Utility lumber at $113.71 per thousand board feet and the Economy at $46.11 per thousand board feet. The composite Utility index used in the study was 0.53 ($113.71) + 0.43 ($46.11) = $84.64 = $85; this value was used for all sample units logged in February 1973. This was done because at present, the most current data the forest manager would have would be for the previous month.

Lumber price index is the price for Douglas-fir dry Commons as reported by WWPA, to the nearest dollar per thousand board feet. The source for this price was the same as noted above. In this case the price is reported directly as Douglas-fir dry Commons, rather than being computed as was the Utility price index. The procedure for use of this price index is the same as described above. For example, in the January 1973 WWPA report the price for Douglas-fir dry Commons is $139.79 = $140. This figure was used for sample units logged in February 1973.

These variables are uniquely defined for this study. This is especially the case for the two "price index" variables. Better measures of prices may well be available for the local areas (Districts). If a new set of price indices can be obtained, they should be incorporated into the program in an attempt to improve the equations.

EXAMPLES

The following examples are included to assist in the interpretation and application of the equations. The volume of logging residue is calculated for one sample unit for each agency. A description of the timber sale characteristics is shown along with the predicted volume and the volume measured in the study. As previously mentioned, logging residue is expressed in terms of cubic feet, gross volume.

BLM, Eugene District

Equation: $$R = 25{,}333.9 - 503.781X_1 + 74.135X_2 + 322.342X_3 - 214.939X_4 + 17.362X_5 + 6.14494X_{11} + 0.00444556X_{13}$$

Sale Situation: X_1 (size of clearcut) = 32 acres

X_2 (average slope) = 33 percent

X_3 (cruise volume) = 139 thousand board feet per acre (Scribner)

X_4 (stand defect) = 15 percent

X_5 (appraised stumpage) = \$97 per thousand board feet

X_{11} = (X_1) (X_3)

X_{13} = $(X_3)^3$

Computation: $R = 25{,}333.9 - 503.781(32) + 74.135(33) - 322.342(139) - 214.939(15) + 17.362(97) + 6.14494(32)(139) + 0.00444556(139)^3$

Results: Gross volume of logging residue computed = 4,586 cubic feet per acre (observed = 3,823 cubic feet per acre)

National Forest, Western Washington

Equation: $R = 2836.1 - 54.555X_2 + 22.705X_3 + 2.4385X_{10}$

Sale Situation: X_2 (average slope) = 29 percent

X_3 (cruise volume) = 40 thousand board feet per acre (Scribner)

X_4 (stand defect) = 34 percent

X_{10} = (X_2) (X_4)

Computation: $R = 2836.1 - 54.555(29) + 22.705(40) + 2.4385(29)(34)$

Results: Gross volume of logging residue computed = 4,566 cubic feet per acre (observed = 3,685 cubic feet per acre)

Table 2 gives the range of values for certain variables by BLM Districts and National Forest areas. These values are taken from the sample data used to derive the equations. These data are shown to assist the forest manager in evaluating the appropriateness of applying the equation to a specific clearcut unit. As previously mentioned, use of the equations should be restricted to clearcut units with characteristics that do not greatly exceed the range of values for the independent variables and study criteria.

Figure 2 shows the location for diameter measurement for a piece of residue material intersected by a line transect. Special cases are shown for lines intersecting the ends of a log. Figure 2(A) shows the intersected face of the log, the place where the defect estimation is made for net volume estimates.

Table 2--*Range of values for selected variables used in predictive equations*

Variable[1/]	Bureau of Land Management equations				National Forest equations	
	Coos Bay	Eugene	Roseburg	Salem	Western Oregon	Western Washington
Clearcut size (acres)	5- 82	9- 73	9-73	10- 66	2/	2/
Average slope (percent)	35- 94	12- 63	2/	15- 71	2/	12- 77
Cruise volume (thousand board feet)	50-264	52-139	20-70	49-120	28-146	31-105
Stand defect (percent)	14- 48	7- 16	18-48	2/	6- 52	2/
Western redcedar (percent)	2/	2/	2/	2/	0- 15	2/
Exportable volume (percent)	2/	2/	2/	2/	0- 80	2/

1/ Does not include price variables or derived variables.

2/ Variable does not appear in the equation for this area.

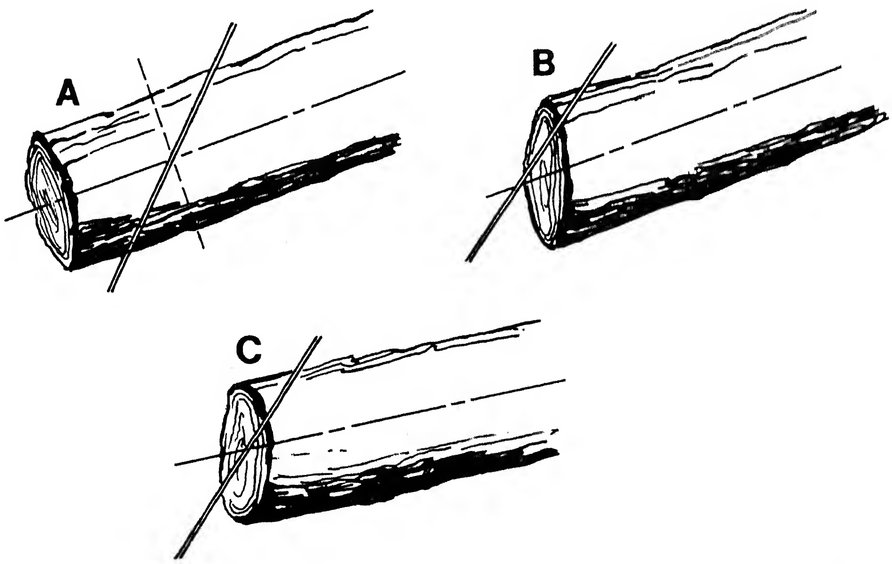

Figure 2.--Location of diameter measurement: (A) each piece is counted and diameter is taken at intersection of transect with centerline; (B) piece is not counted; (C) count every other piece and take diameter at end of piece.

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